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HAZARD ANALYSIS OF POLLUTION ABATEMENT TECHNIQUES. VOLUME II. MANUAL OF HAZARD EVALUATION CRITERIA FOR IMPLEMENTING POLLUTION ABATEMENT PROCESSES AT VARIOUS INSTALLATIONS

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Hercules, Incorporated

Prepared for:

Picatinny Arsenal

June 1974

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FINAL REPORT

HAZARD ANALYSIS OF POLLUTION ABATEMENT TECHNIQUES

VOLUME II OF III

Prepared by

Hercules Incorporated
Allegany Ballistics Laboratory
Cumberland, Maryland

Prepared for

Picatinny Arsenal
Dover, New Jersey

Contract No. DAAA21-73-C-0771

Report No. A0262-520-03-007 HERC No. 75-4

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REPORT TABLE OF CONTENTS

(This report was prepared in three volumes, each with the contents indicated below.)

VOLUME I - Hazards Analysis Report, including Introduction, Summary, Discussion, Tables of Potential Hazards (Fact Sheets) and Bibliography

VOLUME II - Manual of Hazard Evaluation Criteria for Implementing Pollution Abatement Processes at Various Installations, including selected information from Volume I and recommendations regarding potential hazards to be avoided in the design and operation of the subject types of pollution abatement systems.

VOLUME III - Logic Models for the four systems analyzed in Volume I (Appendix to Volume I)

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INTRODUCTION

The objective of the hazard analysis provided by Hercules (ABL), under Contract No. DAAA21-73-C-0771 was to provide a detailed analysis of the hazard potential of two types of pollution abatement processes, adsorption and incineration systems associated with U. S. Army Munitions Facilities. This effort was in conjunction with the Engineering Design Phase of the project. It is, therefore, recognized that this analysis is general in nature, and that more detailed hazard analysis should be directed to specific plant installations.

This manual is intended for distribution to all GOCO locations to delineate the potential problems and required hazard studies necessary to provide a safe full-scale facility. This manual includes:

A. A hazards analysis of the subject systems as they now exist (or will soon exist) in pilot plant form.

B. A list of additional hazards analyses which would be required in order to convert these processes to production scale in compliance with ARMCOM 385-22 and MIL-STD-882.

The detailed companion document to this manual is the final hazards analysis report for the project, presented as Volume I of this report.

Compliance with ARMCOM 385-22 and MIL-STD-882 is best summarized in Figure 1 which is taken from MIL-STD-882. The hazards analysis life cycle is divided into three phases: (1) concept formulation, (2) engineering development, and (3) production. The recommendations in this manual denote the specific studies which should be continued in Phases 2 and 3 based on the information supplied for the initial analysis.

The methodology for accomplishing the required analysis is outlined in ARMCOM 385-22. The Hercules Hazard Evaluation and Risk Control technique (HERC) is designed to accomplish this goal. The correspondence of HERC to these requirements is shown in Figure 2.

Hazard Analysis Life Cycle

CONCEPT FORMULATION PHASE	ENGINEERING DEVELOPMENT PHASE	PRODUCTION PHASE
1. Conduct concept safety studies 2. Perform preliminary hazard analysis 3. Define areas requiring further analysis and/or safety investigation 4. Submit with site location	1. Implement studies designated in previous phase 2. Identify explosives characteristics 3. Identify ignition and propagation sources 4. Identify environmental constraints 5. Furnish design criteria 6. Establish safety objectives 7. Conduct test requirements 8. Conduct human error analysis 9. Evaluate analysis and investigation results; recommend corrective actions 10. Submit with safety submission	1. Assure that safety achieved in previous phase is maintained during production through: identifying critical techniques, procedures, facilities, inspections and tests 2. Audit engineering changes 3. Provide input to training courses and aids. 4. To be made a part of pre-operational survey

FIGURE 1

FIGURE 2

PROPOSED METHODS FOR FULFILLING ANALYTICAL REQUIREMENTS

Requirement (385-22)	Fulfilled (HERC)
1. Process Survey	A. . Process Survey . Determination of Potential Failure Modes . Preparation of "Fact Sheets"
2. Analytical Engineering	B. Analytical Engineering . In-Process Measurement . Laboratory Analysis
3. Sensitivity Evaluation	C. Material Response . Quantitative Initiation Tests . Explosive Reaction Tests
4. Support Studies	D. Engineering Test Measurements . Energy . Force . Velocities . Heat Generation . Failure Rates
5. Hazard Evaluation	E. Quantitative Safety Margins . Design and Operating Criteria

SECTION I

HAZARD ANALYSIS REQUIREMENTS FOR TREATMENT OF TNT PINK WATER BY CARBON ADSORPTION

A. Basis of Analysis

The analysis of this system was based on the existing plant at Iowa Army Ammunition Plant (IAAP). Specific details of the system are those specified for the 40GPM process as it existed in January 1974. The system is shown schematically in Figure 3. The analysis did not include the carbon regeneration process.

B. Hazard Evaluation of the Design Concept

The system analyzed consists of carbon adsorption columns, diatomite filter, circulating pump, settling tanks, sump pump, sump and the floor drain system.

When the system was reviewed for potential hazards, a single source was found that could result in "fire or explosion leading to personnel death or injury or equipment damage." The potential problem is development of a layer of sufficiently dried combustible in or on a process unit. The normal process material (pink water) is so dilute that fire or explosion cannot occur in the fluid.

In the analysis, five initiation modes which could potentially cause initiation were considered. These were:

Impact
Friction
Thermal
Electrostatic Discharge
Electric Current

The material response data utilized in the analysis for potential process contaminant were:

<u>Impact</u> - Dry TNT - 31.6 ft lb/in^2; 25-30% H_2O Wet TNT - 72 ft lb/in^2

<u>Friction</u> - Dry TNT - 190 Kpsi @ 2 ft/sec; 25-30% H_2O Wet TNT - 77.5 Kpsi @ 8 ft/sec

<u>Thermal</u> - Dry TNT - 230°C

<u>Electric</u> - Dry TNT - 0.75J; 25-30% H_2O Wet TNT - 1.26J

Note: These material response values were used in the analysis of the IAAP system. Plants dealing with explosives other than TNT should obtain material response test results for the explosive being processed.

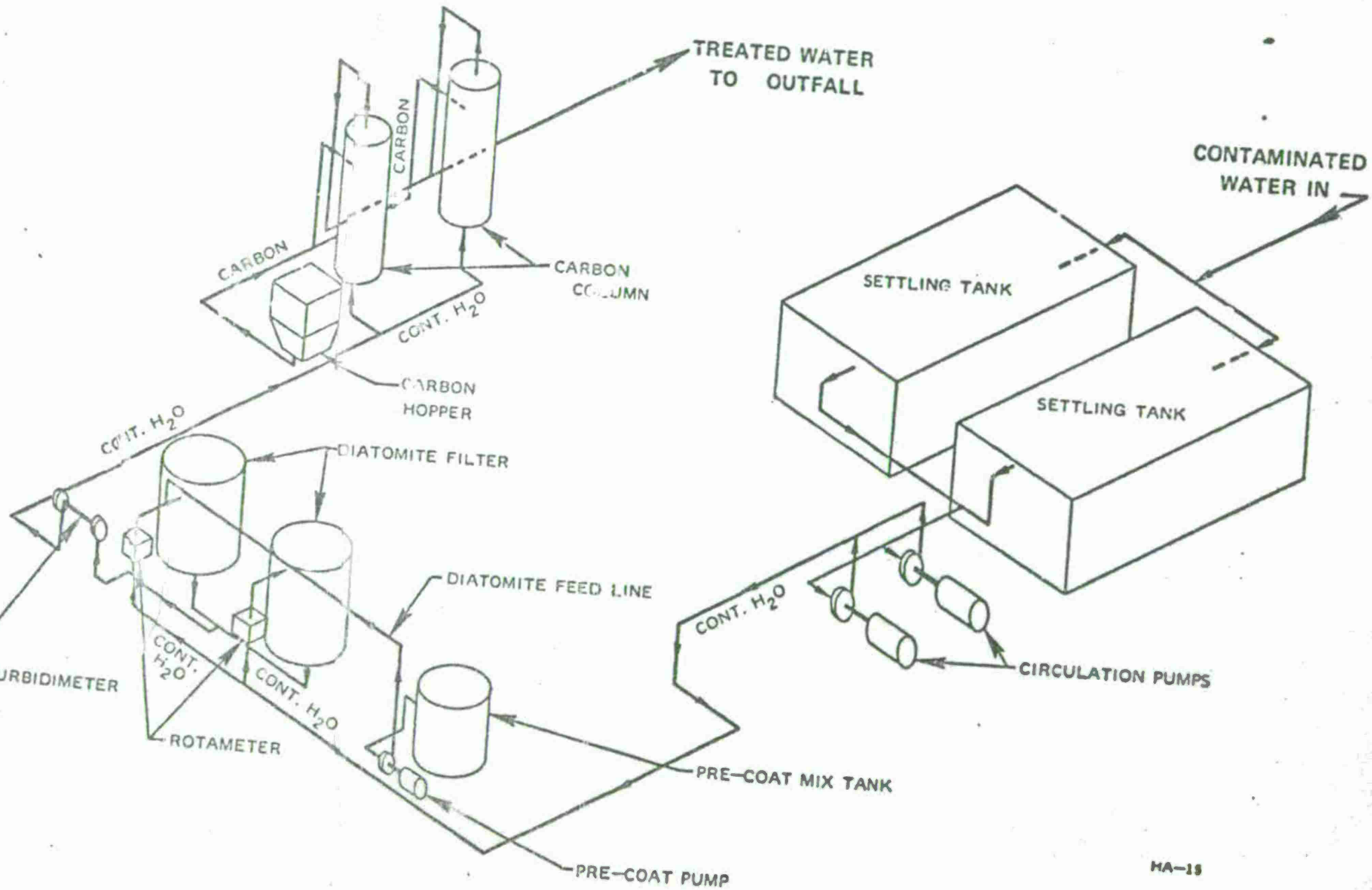

FIGURE 3

Schematic Flow Diagram - Carbon Adsorption Waste Water Treatment Plant
40 GPM Plant (IAAP)

1. Carbon Adsorption Column Analysis

Two identical carbon columns are each packed with activated carbon which adsorbs dissolved TNT from the water in the final process steps. Water from a diatomaceous earth filter enters the bottom of the carbon bed and flows through the bed. The effluent from the first column is pumped to the bottom of the second column where the adsorption process is repeated, after which the water is discharged to the sewer. Either column can receive flow from the filters, thus ensuring that the last column will have the freshest carbon. The columns are serviced when they do not produce water with less than 5 ppm TNT.

The analysis revealed 20 sequences of independent events which could potentially generate a fire in the column. Ten each came from two independent sequences by which a sufficiently dry TNT or nitrobody layer could be produced.

a) Sources of Combustible

The sources of combustible are as follows:

(1) Dry layer accumulating in the inlet due to the bed drying at the edge, or filtered TNT accumulating at the column surface.

(2) Chemical reaction of the propellant or explosive waste (PEW) in the column.

b) Sequences that could lead to the Initiation of the Combustible

(1) Faulty electrical instrumentation in the column (electrical power)
(2) Electrical discharge from a tool or motor (electrical power)
(3) Human ESD (ESD)
(4) Fire from adjacent unit (thermal)
(5) Welding (thermal)
(6) Mechanical stimulus by maintenance man (friction)
(7) Movement of bed containing tramp metal (friction)
(8) Dropping of tool (impact)
(9) Tramp metal in the carbon bed (impact)
(10) Impact of carbon bed when filling or emptying carbon column (impact)

Two of the 20 sequences had probabilities of occurrence equal to or greater than 10^{-6}. These were (a) impact of carbon onto a combustible layer when filling or emptying the vessel, and (b) welding operations, assuming the maintenance man does not check for existence of and remove a combustible layer. A summary of the various ignition modes with their safety margins and probabilities and also the maximum probability calculated for the existence of sufficiently dry combustible

layer, is shown in Volume I.

A check of the vessel prior to filling, emptying, or a welding operation would decrease the probability of a fire or explosion provided that any explosive layer is removed before the indicated operation begins. This would then be an acceptable hazard.

c) Future Analysis Requirement

The potential problems identified for the carbon columns are related to maintenance operations or regeneration of the carbon. Future analysis requirements are as follows:

(1) Engineering Development Phase

(a) Perform studies to identify the quantity of TNT or other explosives in the material as a function of time, through-put and location of the carbon.

(b) Identify the explosive characteristics of the carbon columns as a function of TNT or other explosives level including:

Impact
Friction
Explosives Propagation

(c) Design joints and closures to prevent mechanical initiation stimuli and contamination with combustibles.

(d) Perform hazard analysis of the regeneration operation.

(2) Production Phase

During this phase, the identified handling problems can be resolved since the potential hazards are related to maintenance and operating personnel exerting mechanical or electrical stimulus to TNT dust layers.

d) Hazard Criteria

The potential reactions in the carbon columns should not be explosive and can be controlled without major injury, therefore, this subsystem should be considered a category II problem as defined by ARMCOM 385-22.

2. Diatomite Filter Analysis

The cylindrically-shaped filter has dished ends and is mounted vertically on legs. Its removable top is supported by a swivel arrangement to allow the lid to be raised and swung to the side when servicing. Circular stainless steel cartridges mounted at the top of a vertical pipe support the filtering media. Each cartridge consists of an upper perforated plate fastened to a lower solid dish filled with baffles. A polypropylene bag surrounds each cartridge and is used to form a base for

the diatomaceous earth filtering media. When the filter is serviced, the plates and supporting pipe are lifted from the filter vessel by a crane.

During operation, waste water and diatomaceous earth enter the filter, and flow over the cartridges. Water flows through the earth layer and leaves through holes in the supporting pipe at the bottom center of the filter. This effluent water normally is free of suspended particles and contains only dissolved TNT. The filter must be cleaned periodically, since continued operation results in reduction of capacity to an unacceptable level.

a) Source of Combustible

The potential problems associated with the diatomite filter are similar to those identified for the carbon columns in that the potential hazard should exist only if dry concentrations of explosive waste occur in places where they can be exposed to initiation stimuli. A summary of the potential problems and the analysis are included in Volume I of this report.

Preliminary testing of spent diatomaceous earth samples taken from the Joliet AAP indicates that the material is insensitive to initiation when wet and contaminated with 8% TNT, since it will not react explosively to the firing of a J-2 cap. Dry material, however, is sensitive to initiation and may result in localized initiations. This is due primarily to the existence of lumps of TNT which react with the same sensitivity as pure TNT.

The four critical initiation stimuli present in the system are:

(1) Impact initiation from diatomaceous earth during filling or emptying the filter, if a sufficient layer of dry explosive is present.

(2) Frictional initiation during maintenance when a tool is rubbed over a sufficiently dry combustible layer.

(3) Frictional initiation from movement of diatomaceous earth when a combustible layer is sufficiently dry and located on the vessel wall.

(4) Thermal initiation during welding operations when a combustible layer exists. This assumes that the maintenance man does not check for and remove combustible material before a welding operation is started.

b) Future Analysis Requirements

The potential problems identified for the diatomite filter are related to maintenance operations or regeneration of the filter

media so studies of the potential for hazards in these areas should be continued in the engineering phase. It should be noted that an item of major concern is the concentration of explosive material in the media, since the filter accumulates particulate waste, and the concentration of explosive could be quite high.

c) Hazard Criteria

Potential reactions in the diatomite filters should not be explosive and can be controlled without major injury, therefore, this subsystem is considered a Category II situation, as classified by ARMCOM 385-22.

3. Circulating Pump, Settling Tank, Sump Pump, Sump and Floor Drains

The pink water at IAAP originates in various processes and is collected as waste by floor drains (trenches) The waste water is then channeled to a sump, from where it is pumped to a settling tank. The baffled tanks allow large particles to settle, after which the contaminated water is pumped to the diatomite filters via a centrifugal pump.

a) Sources of Combustible and Initiation

Potential problems associated with these components are not related to normal operation but are due to operation when the combustible becomes concentrated or dry.

Sources of initiation of concern are frictional and thermal stimuli that can be present in the pumps if the waste material pumped is highly concentrated, or manual shoveling of bulk waste from the sump during cleanup. A secondary item of concern is system cleanliness when maintenance operations such as welding occur. During such operations, small pockets or films of explosive waste could be initiated, causing localized reactions and possible personal injury. Detailed results of the hazard analysis are included in Volume I of this report.

b) Future Analysis Requirements

Future analysis criteria are the same for this system as for the other components in the carbon adsorption system, with additional emphasis in the engineering design phase to develop sufficient instrumentation or safeguards to prevent pumping concentrated waste through the feed or sump pump, or to prevent excessive mechanical stimuli when emptying sumps (possibly by utilizing non-sparking tools).

c) Hazard Criteria

The hazard criteria for this zone of the system is considered to be category III, as described in ARMCOM 385-22 since reactions in the pump or the sump could be explosive, causing damage and/or injury.

SECTION II

HAZARD ANALYSIS REQUIREMENTS FOR MOLECULAR SIEVE FILTERING OF TAIL-GAS FROM A NITRIC ACID PLANT

A. Basis of Analysis

The molecular sieve process analyzed in this study was the proposed system for treatment of tail-gas from the 55-ton per day nitric acid plant at Holston Army Ammunition Plant, as described in a letter from Mr. W. C. Miller of Union Carbide to Mr. Alfred Tatyrek of Picatinny Arsenal(1). The nitric acid plant tail-gas comes from the ammonia burner and passes through an absorption tower before entering the molecular sieve system. A schematic of the system is shown in Figure 4.

B. Hazard Analysis of the Design Concept

In the molecular sieve system considered here, the tail-gas is first passed through a feed chiller, which cools the gas, condensing vapors, and then through a mist eliminator, where condensate is removed from the stream. The gas stream then goes to the molecular sieve, where nitrogen oxides are absorbed by the adsorbent/catalyst before the gas is vented to the atmosphere.

Two identical catalyst/adsorbent vessels are provided so that one can be used in the adsorbing cycle while the other is being regenerated. Part of the exhaust gas from the adsorbing unit is fed to the regeneration system where it (the gas) goes through a compressor, a steam heater, an electric heater, the vessel being regenerated, a recycle gas cooler and a knockout drum before being fed back into the absorption tower. During this cycle, the adsorbent/catalyst is cleaned so that it can be used again in the adsorbing cycle. Just before the regenerated adsorbent/catalyst vessel is placed back on stream, it is cooled by changing the regenerating gas stream flow from the steam and electric heaters to a cooler and chiller, so the vessel is at the proper temperature when it is returned to the adsorbing cycle.

Preliminary hazard evaluation of this system has not defined any unacceptable hazards during normal operation, since the material present is not flammable.

It is possible that a combustible mixture could result from an abnormal situation. It would require both larger than normal quantities of oxidizer (more NO_x, HNO_3, O_2, or NH_4NO_3) and a fuel source such as a bearing leaking oil or oil left inside a unit after maintenance. NH_4NO_3 is normally not present in the tail-gas but does exist in the HNO_3 process.

In the analysis of "off-gas" mixtures of nitric acid "tail-gas" containing an oxidizer and a fuel, the following modes of initiation were considered:

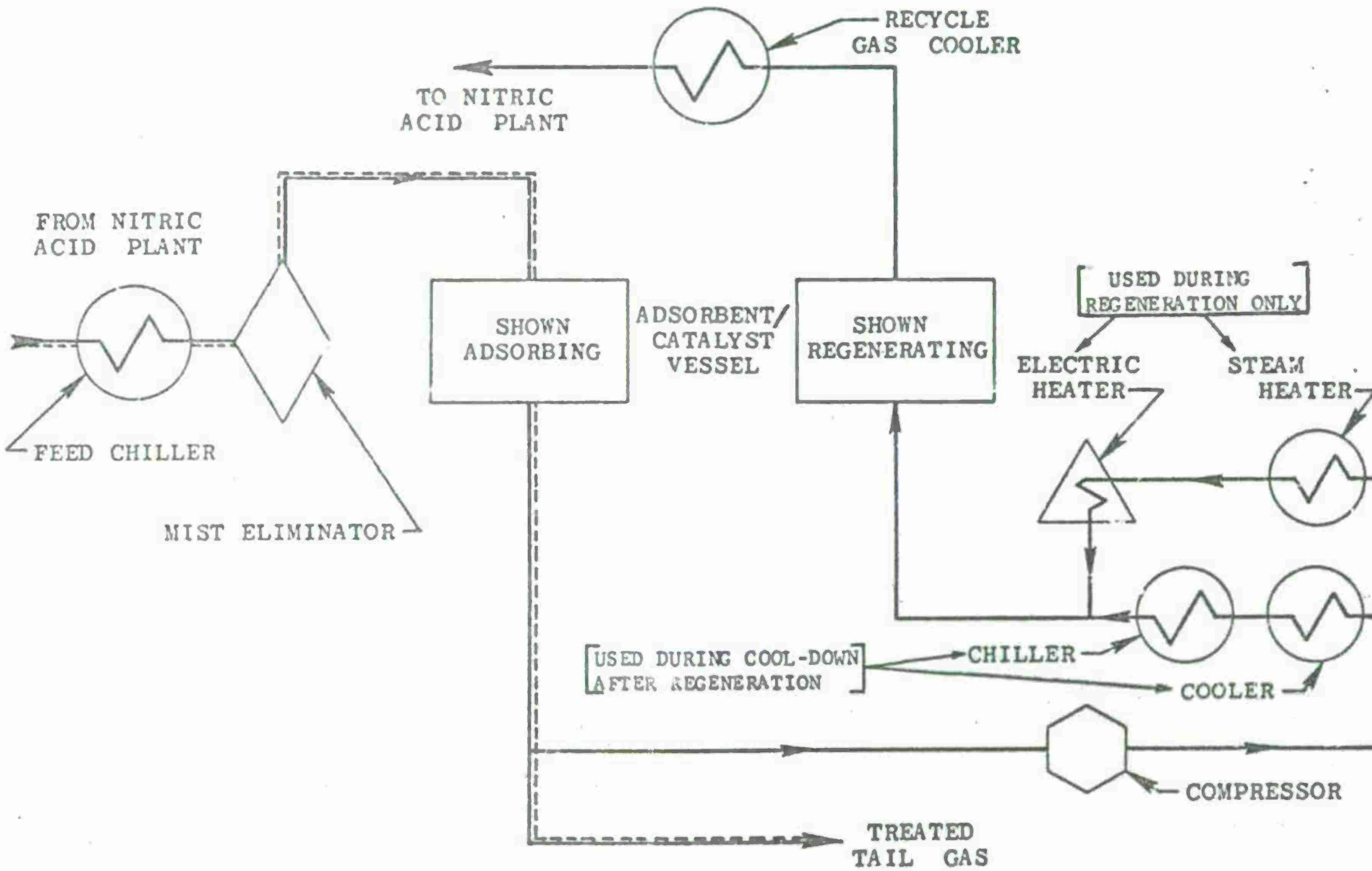

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FIGURE 4

Molecular Sieve System

1. Impingement
2. Thermal
3. ESD
4. Electric Current

For possible "off-gas" deposits, the following additional modes of initiation were considered:

1. Impact
2. Friction

The sensitivites of representative materials considered in the analysis are:

Thermal -	Stoichiometric mixture of nitric acid and oil in water 265°C [97.76% Nitric Acid (62%) + 2.24% oil (Premium Turbine Grade)]	
Electrical -	NH_4NO_3/HNO_3/oil/H_2O [43.5/33.5/2.5/20.5]	0.075J
	NH_4NO_3/oil [94.5/5.5]	0.075J
Impact	NH_4NO_3/oil [94.5/5.5]	>61.5 ft-lb/in^2
	HNO_3/H_2O/oil [60.6/37.2/2.2]	>179K ft-lb/sec
	$HNO_3/H_2O/NH_4NO_3$/oil [33.5/20.5/43.5/2.5]	>179K ft-lb/sec

1. Feed Chiller

The feed chiller normally cools the tail-gas from the absorption tower from 38°C (100°F) to about 10°C (50°F). This condenses most of the water and the nitric acid formed by the reaction between water and nitrogen dioxide. The tail-gas is usually noncombustible, typically containing 96 percent (by weight) inert nitrogen, some oxidizers and no fuel.

a) Source of Combustible and Initiation

The identified sources of a combustible "off-gas" deposit are:

(1) Chemical reaction
(2) Condensate forms in unit due to temperature change

The controlling factor in each of these is the presence of a fuel (oil) and oxygen.

The potential sources of initiation identified are:

(1) Condensed or particulate "off-gas" strikes the vessel wall. (Impingement)
(2) Tramp material strikes the deposited "off-gas." (Impingement)
(3) Welding during maintenance causes a fire. (Thermal)
(4) Fire enters from an adjacent unit. (Thermal)
(5) Electrostatic energy is produced by flowing process stream or operators. (ESD)
(6) Electrical energy is released by faulty tools or instrumentation. (Electrical Power)

The identified problems causing a flammable mixture are:

(1) Gas entering the chiller inlet exceeds lower flammable limit.
(2) Gas in chiller goes into the flammable range due to a change in temperature or pressure.
(3) Chemical reaction forms flammable material.
(4) Flammable mixture forms during equipment shutdown.

The existence of either a flammable gas mixture or a combustible "off-gas" deposit is unlikely, since either situation would result only in case two abnormal events occur at the same time, such as the accidental presence of oil and at least one other simultaneous accidental failure such that sufficient oxidizer was present. The analysis showed two ways in which such a deposit could occur and four ways by which a flammable cloud could exist.

b) Future Analysis Requirements

The analysis indicates that it is extremely remote that any hazard will occur in this unit. It also indicates that the controlling factors of concern are:

(1) Presence of:
   (a) Oil
   (b) Oxygen
   (c) Chemicals from other parts of the process
   (d) Faulty electrical equipment or instrument
   (e) Maintenance operations

In both the Engineering Development Phase and the Production Phase, additional effort is required to identify and correct design defects or procedural situations that will allow the above identified events to occur.

2. Mist Eliminator

The mist eliminator removes entrained water and nitric acid from the tail-gas by passing the incoming stream through condensed liquid previously accumulated. The entrained liquid that is not picked up in the accumulator is "knocked out" of the gas by a fibrous (loosely woven) gas deflector at the top of the eliminator.

a) Potential Hazards

As with the feed chiller, a major malfunction would be required to produce a combustible mixture. The existence of either a flammable gas mixture (two ways identified) or a combustible "off-gas" deposit (four ways identified) is unlikely, since either situation would require at least two abnormal events to occur at the same time, similar to those proposed above for the feed chiller.

b) Future Analysis Requirements

The analysis of this system is directly analogous to the analysis of the feed chiller. The future analysis requirements and hazard category are, therefore, the same.

3. Adsorbent/Catalyst Vessel

This unit is the principal unit in molecular sieve operation. Two such units exist such that one can be adsorbing when the other is being regenerated. In the adsorption operation, water, nitric oxide, and most of the nitrogen dioxide are selectively adsorbed onto the adsorbent/catalyst. In the regeneration operation, water and nitrogen dioxide are released from the adsorbent/catalyst. Regeneration is accomplished by heating the stream going to the adsorbent/catalyst, and then in order to make the subsequent adsorption operation more efficient, the regeneration vessel is cooled before putting it back into the adsorption cycle.

a) Hazard Evaluation of Adsorption Phase

The adsorption process is exothermic, such that the incoming stream is typically heated from 13°C (55°F) to 35°C (95°F). The process streams are normally not combustible, containing only oxidizers and inert nitrogen (about 96%). A major upset would be required to produce a combustible mixture. Thus, the probability of existence of a combustible layer is low. For a combustible vapor, the maximum probability was calculated to be 10^{-9} (five ways identified) since vapors should be of a more inert nature than an accumulated layer.

The undesired event could be potentially caused by 67 different minimum sequences of events identified by the hazard analysis.

Since a combustible for impingement has not been identified for this process, only 52 different sequences are applicable. Of these, none has a probability greater than or equal to 10^{-6} because of the low probability of sufficient combustible material existing. A summary of the potential initiation modes, with safety margins and calculated probabilities of occurrence of the indicated hazards is presented in Volume I of this report.

b) Future Analysis Requirements

The future analysis requirements for this subsystem are the same as for the feed chiller since similar conditions exist. Additional items that are of concern are overheating of the regeneration compressor, failure of the regeneration valve (opening of the regeneration valve to the adsorbent/catalyst vessel), and overheating of the electrical heater. These items should be investigated more thoroughly during the Engineering Analysis phase.

c) Regeneration Phase

The removal (desorption) of nitrogen oxides and water from the adsorbent/catalyst is an endothermic process. Heat is supplied by heating a portion of the exit stream from the other adsorbent/catalyst vessel in which adsorption is occurring. Typically this stream is heated from 35°C (95°F) to 288°C (550°F). The gas stream is normally non-combustible, typically containing 96% inert nitrogen, about 3% oxygen and traces of nitrogen dioxide.

As with the other process unit discussed, a major upset would be required to produce a combustible mixture. The normal proportion of oxidizer is small (about 6%) and normally no fuel is present. A maximum probability of 10^{-9} was calculated for the existence of either a flammable gas mixture (four ways identified) or a combustible "off-gas" deposit (one way identified) since either situation would require at least two simultaneous accidental events. A summary of the potential initiation modes is shown in Volume I of this report, with safety margins and calculated probabilities of occurrence of hazards and the maximum probability of existence of flammable material.

4. Other Selected Components

Hazard evaluation of the following units identified similar problems as for the feed chiller and adsorbent/catalyst vessels since the process stream is the same. The potential problems and safety margins for each are shown in Volume I of this report.

No need for future analysis of these units is anticipated, except to: (1) evaluate engineering design modifications, and (2) evaluate final operating procedures.

a) Regeneration Compressor

The regeneration compressor provides sufficient pressure to feed the adsorbent/catalyst vessel during regeneration. This compressor performs the same function during regeneration cooling as during regeneration heating. The only difference is that during regeneration cooling the compressor receives gas from near the end of the adsorption operation, whereas during regeneration heating, it receives gas from the beginning of the adsorption operation. Near the end of the adsorption operation, the adsorbent/catalyst would not have as good adsorption characteristics since most of its adsorption sites would be filled and more oxidizer would be in the gas stream. However, under normal circumstances, no fuel and little oxidizer (about 3%) are present.

During its operation, the compressor typically pressurizes the stream from 77.6 psig to 110 psig while heating the stream from 35°C (95°F) to 79°C (175°F).

b) Regeneration Gas Steam Heater

The regeneration gas steam heater is connected directly to the outlet of the compressor. Steam is used to heat the compressed gas for the regeneration heating operation. The gas is typically heated from 79°C (175°F) to about 182°C (360°F).

c) Regeneration Gas Electric Heater

The regeneration gas, as it leaves the steam heater is further heated in the electric heater to 288°C (550°F).

d) Regeneration Cooler and Gas Chiller

The regeneration cooler and gas chiller are connected in series to the compressor discharge and are used only during regeneration cooling. They cool the discharge from 79°C (175°F) to 66°C (150°F).

e) Recycle Gas Cooler

The recycle gas cooler cools the gas from the adsorbent/catalyst vessel during regeneration before it combines with the nitric acid stream entering the knock-out drum. During regeneration heating, this stream is cooled to 260°C (500°F) and it is cooled to 21°C (70°F) during regeneration cooling.

SECTION III

HAZARDS ANALYSIS REQUIREMENTS FOR THE FLUIDIZED BED INCINERATOR

A. Basis for Analysis

The basis for the fluidized bed system was provided by the specifications for modification of the vertical incinerator at Picatinny Arsenal to utilize a fluidized bed. This system was based on research at Esso Research and Engineering Company and did not include getting the propellant/explosive feed slurry to the bed. The system is shown in Figure 5.

B. Hazard Evaluation of the Design Concept

Several process units were considered in this study. The air intake filter mufflers, blower (compressor), and discharge muffler normally deliver particle-free air to the burner and the bed. The burner serves as the ignition chamber for fuel oil, which subsequently burns in the preheater before entering the plenum for further combustion. These hot burning gases flow into the bed chamber through a grid which separates the bed from the plenum. The hot gases fluidize the bed contents which are composed of the bed material (alumina base), the slurried propellant or explosive, and auxiliary fuel oil, if necessary. The combustion products are carried, as a gas particulate stream, into a cyclone separator, from which normally particle-free gas flows into the stack.

The process is carefully controlled by a "Flame Guard" in the preheater, and an operational control center. The operational control contains interlocks for sequential operations and alarm conditions and blocks certain circuits until proper operating conditions have been met.

1. Combustible Materials

Four fuel sources were considered for the undesired event of unusual "fire or explosion which could result in personnel death or injury or equipment damage." The four sources are as listed below:

a) Normally occurring fuels

(1) Natural gas (from the pilot gas at the burner)
(2) Fuel oil from the burner
(3) Auxiliary fuel oil to the bed

b) Propellant or explosive entering as slurry feed to the bed, or remotely as a pollution dust from the air intake filter muffler

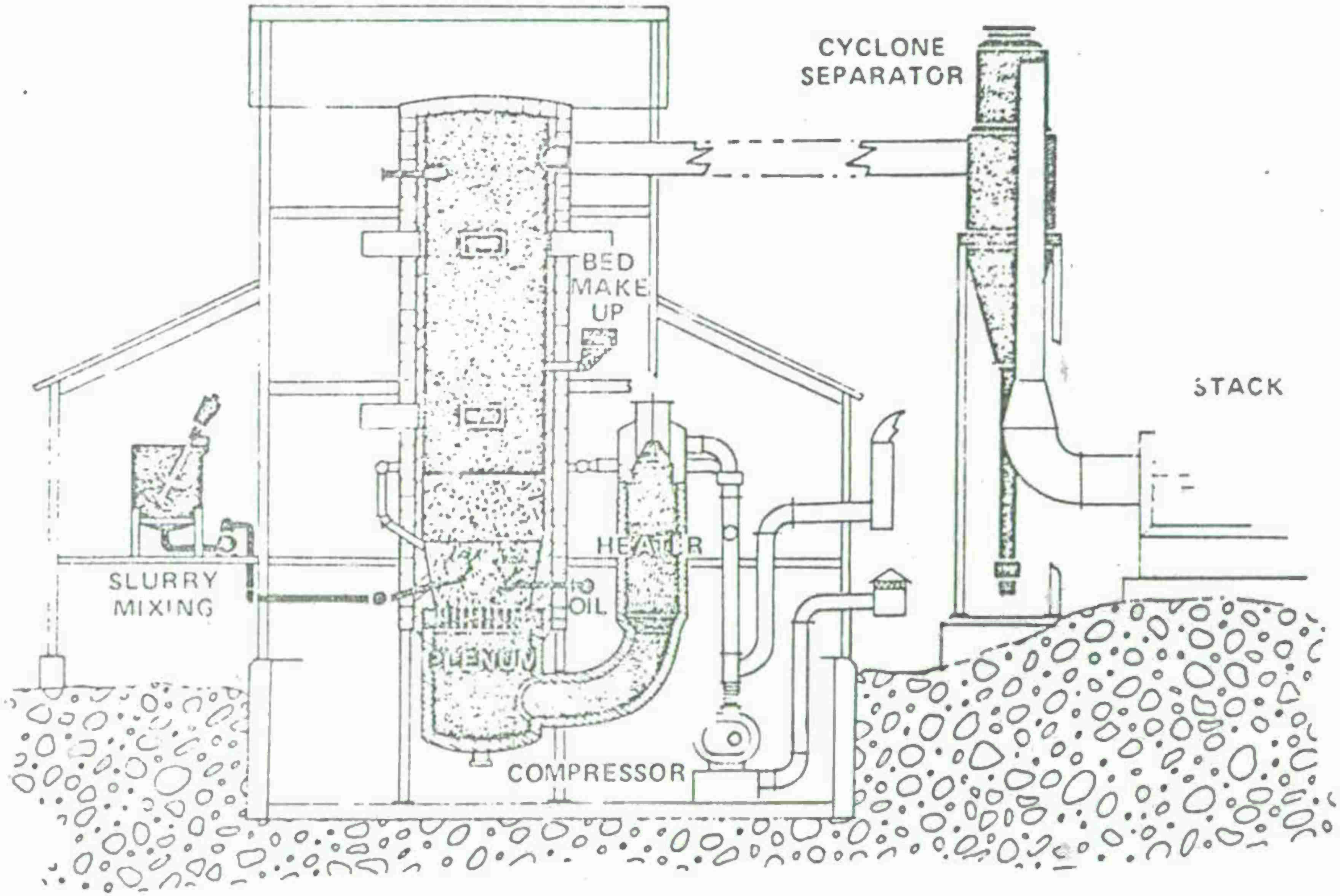

Figure 5   Picatinny Arsenal Fluidized Bed Incinerator

c) Unburned propellant or explosive layer or byproducts of the propellant or explosive

d) Vapor cloud of vaporized unburned propellant or explosive.

2. Material Response Data

A preliminary analysis was performed utilizing the sensitivity of several possible materials for evaluation purposes as follows:

Impact	-	M1 Propellant	3.8 ft lb/in^2
	-	TNT	31.6 ft lb/in^2
	-	N5 Propellant	
Friction	-	M1 Propellant	
	-	TNT	190 Kpsi @ 2 ft/sec
	-	N5 Propellant	34 Kpsi @ 2 ft/sec
Thermal	-	M1 Propellant	120°C
	-	TNT	230°C
	-	N5 Propellant	150°C
ESD	-	M1 Propellant	0.013J
	-	TNT	0.075J
	-	N5 Propellant	0.075J
Impingement	-	M1 Propellant	>10,000 ft/min
	-	TNT	38,000 ft/min

C. Hazard Analysis of Subsystems

1. Air Intake Filter Muffler

Air being supplied to the fluidized bed enters the process through the air intake filter muffler. At the time of the analysis, the specifications of the intake muffler were not known by Picatinny Arsenal. Consequently, the assumption was made that the filter material was of the fibrous cloth type, which is combustible and capable of generating an electrostatic charge. Initiation of the filter material, however, was considered very unlikely.

The presence of fuel oil and pilot gas in the air intake muffler were not considered, due to the barrier created by the air blower between the burner and the intake muffler when the blower is not operating. When it is operating, air from the blower transports these fuels further away from the muffler.

Two other fuel sources whose presence was considered unlikely were analyzed in detail. The fuel sources were the previously discussed combustible (propellant or explosive material or byproducts) layer and cloud. The analysis identified 60 minimum sequences of events which potentially cause the undesired event of "fire or explosion resulting in equipment damage or personnel injury or death." Thirty-three applied to a combustible layer and 27 to a cloud. Three independent sequences by which either a cloud or layer could develop in the intake filter were described in the logic model. These are:

- Combustible waste in air
- Filter cloth not changed
- Combustible waste passed through the cloth

Several initiation modes were considered in this system, such as:

- Friction and impact by tools during maintenance operations.
- Friction due to tramp material in the muffler
- Vibration of loose components in the system
- Impingement of slugs of combustible breaking free in the muffler
- Thermal stimulus from welding or fire in adjacent buildings
- Human and electrostatic discharge

Summaries of the initiation modes for the intake filter are shown in the Tables of Volume I. These describe the safety margins and probabilities calculated for these initiation modes as well as the maximum calculated probability for the existence of fuel.

a) Future Analysis Requirements

(1) Engineering Development Phase

The potential problem identified for this unit is contamination entering the system, and initiation of combustible layers during manual operations such as maintenance. During the engineering development phase, analysis should be concentrated on the following:

- Design of holding fixtures and components such that excessive initiation stimuli cannot be applied to the potential explosive contaminants.
- Location of the intake muffler away from potential sources of combustible materials to prevent contamination.
- Review and redesign internal components that could fail and act as tramp metal.
- Review of instrumentation.

(2) Production Phase

The majority of potential initiation hazards that could exist in this unit are related to human/equipment interface problems; therefore, during the production phase all operating procedures should be reviewed, with concentration on potential problems in maintenance, filter change cycle, and operating procedures.

2. Air Blower

A constant displacement-type blower supplies air for combustion fluidization and flue gas quality control. It is started manually. A

time-delay (TDR-1) relay on the manual start-stop switch controls the solenoid valve (SV-102) on the outlet of the pressure controller (PC-1) to allow the butterfly valve (BV-101) to remain open, venting the blower to atmosphere during starting, and thus preventing pressure buildup in the preheater.

At expiration of design delay time, relay TDR-1 operates, causing valve SV-102 to open, allowing pressure controller PC-1 to modulate valve BV-101 in order to maintain a pressure of about 6.2 psig in the air supply line.

a) Combustible

All four fuel sources identified for the undesired event in the fluidized bed system were considered for the air blower even though their probabilities are low. One-hundred and twenty-nine sequences which could lead to the undesired event were considered. Thirty-six came from three independent sequences identified for producing a combustible layer; thirty were associated with fuel oil; and twenty-eight were associated with natural gas. The maximum probabilities calculated for the existence of sufficient fuel were extremely low. Since all probabilities of the presence of fuel for the undesired event, and for initiation of fuel, were low, no unacceptable hazard was identified for the air blower.

Summaries of the initiation modes for the air blower are shown in the Tables of Volume I, describing the safety margins and probabilities calculated for these initiation modes as well as the maximum calculated probability for the existence of fuels.

3. Discharge Muffler

The discharge muffler decreases the noise level of an auxiliary stream from the air blower to an acceptable level. This side stream also helps control the air supplied to the fluidized bed.

Since the discharge muffler is downstream of the air blower, a path exists for fuel oil or pilot gas to migrate to the discharge muffler when the air blower is not operating. Thus, fuel oil and pilot gas can be considered along with a combustible layer and cloud, as potential fuel sources. The analysis, however, indicates all probabilities of sufficient fuel for the undesired event to occur are low.

The initiation modes for the discharge muffler are summarized with their safety margins and probabilities in Volume I. The maximum calculated probability for the existence of fuel is also presented there.

c) Future Analysis Requirements

(1) Engineering Design Phase

The basic problem associated with the discharge muffler is the potential existence of flammable vapor due to fuel oil or pilot gas

migrating into the system. During the engineering design phase, analysis should be concentrated on:

- o The pilot gas system (specifically providing for redundant safety controls)
- o The fuel oil system (for possible flow paths)
- o The possibility of utilizing detectors to shut down the system if a critical condition should occur.

4. Burner

The burner is the primary initiation chamber for fuel oil supplied to the grid.

Startup of the burner is critical to operation of the system. Blower air must be available at some minimum flow rate through the combustion air controller (FC-2) and the control valve (V-105). The start button (FB-1) is then pressed and held to activate the Flame Guard, the pilot gas solenoid valve control, and the electrical igniter for the pilot gas. (Details of the ignition system were not available, so the analysis is general.)

At the command of the burner control (FC-2), solenoid valve SV-203 opens to introduce oil to the proportionating control valve. An internal bypass (V-204) is set to a minimum ignition flow if high pressure atomizing air is available at the pressure switch (PS-6) and the temperature controller (TC-1) is set to an internal low temperature limit.

The Flame Guard takes over as soon as the Flame Guard Eye senses a proper oil flame at the burner, and the start push button may be released. If the flame is not recognized within a set time, SV-203 is de-energized, and the oil supply is shut off. SV-203 is also closed instantly if the Flame Guard Eye senses a blow-out, or no flame, and manual restart must then be initiated. Numerous sequences of events were considered as potential causes of hazard in the burner, however, all were very unlikely, and are considered acceptable hazards.

Summaries of the various initiation modes with their probabilities and safety margins are presented along with the maximum calculated probability for the existence of sufficient fuels in Volume I.

a) Future Analysis Requirements

(1) Engineering Development Phase

The only future analysis required on the burner design is to review the start and emergency shutdown controls for adequate "fail-safe" features. The actual design was not available for the preliminary analysis.

5. Preheater

Fuel oil that is ignited in the burner is transported by the air stream into the preheater. This preheater is a large chamber into which the burner opens. The previously mentioned Flame Guard is actually located in the preheater.

Four fuel sources considered were the same as for the burner.

The analysis of the preheater did not uncover any unacceptable hazard sequences.

Summaries of the initiation modes for the preheater are shown in Volume I. These describe the safety margins and probabilities calculated for these initiation modes as well as the maximum calculated probability for the existence of fuels.

6. Plenum

The gas from the preheater flows into the plenum where it is further consumed.

The initiation modes, however unlikely, for the plenum are summarized with their safety margins and probabilities in Volume I. Also included in these tables are the maximum probability for the existence of sufficient combustible materials.

7. Grid

The grid serves two principal purposes. It helps distribute the gas flow uniformally throughout the bottom of the bed, and also separates the fluidized bed from the plenum.

The analysis indicated 185 potential hazard sequences; however, none were unacceptable due to the low probabilities calculated for existence of sufficient fuel.

Summary information concerning the initiation modes with their safety margins and probabilities, and the maximum calculated probability for the existence of sufficient combustible materials are shown in Volume I.

8. Fluidized Bed

Combustion of the slurried propellant or explosive is the primary operation performed in the fluidized bed. Other operations such as adding makeup bed material are also considered.

Most feeding operations are semi-automatic and have control interlocks. One example is the in-bed oil feeding operation as the fluidized bed temperature is raised to the fuel oil autoignition temperature during

startup, the oil low bed temperature control (TC-3) will indicate by glowing lights that the in-bed injection oil circuit may be activated. Activation before this point is prevented by an interlock in the flow control center (FC-3) and the safety and operational control panel (CP-1). However, the possibility of an erroneous (too high) reading from TC-3 could over-ride the interlock. Consequently, careful check must be made by the operator before activating the in-bed injection oil circuit.

By activiation of an acknowledgement button on the safety control panel (CP-1), one or more pairs of oil injection nozzles (SV-209 to SV-214) may be opened to a minimum flow at the command of a flow control in the in-bed oil flow control center. The number of oil injection nozzle pairs used is at the discretion of the operator They may be activated or deactivated through the in-bed oil flow control center, which will block the temperature controller (TC-4) output to in-bed oil flow control center (FC-3) in the event that the oil low bed temperature limit control (TC-3) falls below the minimum ignition temperature of the oil.

The flow, as set by (FC-3), is increased gradually to obtain a predetermined temperature, at which time a low temperature control (TC-5) will indicate to the slurry control center (FC-4) that the slurry valves can be opened or activated.

Before the slurry can be injected into the bed, the operational control center (CP-1) requires that the blower is started, the preheater burner is igniting the fuel oil, and the in-bed injection system activated. In addition, it assures that the oil pressure switch (PS-5) on the oil to control valves (V-206, V-207, V-208) is activated and a minimum fluid bed temperature of 1300°F to 1650°F is sensed by the slurry low temperature control (TC-5).

The slurry injection nozzles are all supplied by one control valve (FC-301) during normal operation but may be individually shut off and purged remotely by a remote nozzle purge selector switch center. When the minimum fluid temperature is reached, TC-5 plus PS-5 in the oil injection line and PS-1 in the purge water line allow the slurry injection valve (FV-301) to be operated.

During normal shutdown procedures, the slurry control center stop button (PB-3) is pressed, deactivating the slurry supply valves and activating the slurry nozzle flush cycle. The emergency back-flush procedure should be followed shortly thereafter.

The primary function of control panel (CP-1) is to prevent slurry from being injected into the fluid bed before proper ignition conditions are obtained, and to prevent slurry from remaining in the header lines after system shutdown due to an alarm condition.

Four situations constitute an alarm condition. They are (1) loss of main injection oil pressure, (2) lowering the fluid bed temperature below the predetermined combustion temperature of the slurry, (3) an

excessively high temperature either above the bed or at the entrance to the cyclone separator, and (4) loss of fluidizing air pressure either by loss of electrical power for the blower, or malfunction of the butterfly valve feeding air through the preheater to the plenum chamber.

The in-bed oil flow center is under the control of the operational control center and can have its total oil shut off (and be deactivated) by (1) decreased fluidization (minimum under grid plenum pressure), (2) reduced cooling water pressure, or (3) minimum alarm temperature in the top of the incinerator tower (TI-7).

Summaries of the initiation modes for the bed are shown in Volume I. These describe the safety margins and probabilities calculated for these initiation modes as well as the maximum calculated probability for the existence of fuel.

a) Future Analysis Requirements

(1) Engineering Development Phase

The control system for activating, feeding and monitoring the bed should be extensively studied during this phase to define sequences that could cause abnormal concentration and initiation of combustibles.

9. Cyclone Separator and Stack

The cyclone separator is a vertical cylinder with a conical bottom, a tangential inlet near the top, and an outlet for dust near the bottom of the cone. It removes particulate matter from effluent gas coming from the bed, and passes the gases to the stack, from which the gases are released to the atmosphere.

The same two fuel sources, a combustible layer and a combustible cloud, apply to the cyclone separator and to the stack. None of the potential initiation modes examined resulted in an unacceptable hazard due to the low probability of fuel.

Summaries of the initiation modes with their safety margins and probabilities are shown in Volume I, along with the maximum probabilities for the existence of fuel.

a) Future Analysis Requirements

No future analysis is identified for the cyclone separator or stack areas.

b) Hazard Criteria

The fluidized bed is considered a Category III hazard (ARMCOM 385-22) due to the potential initiation of relatively large quantities of gas or fuel oil if a critical sequence of events should occur.

SECTION IV

HAZARD ANALYSIS REQUIREMENTS
FOR THE INCINERATION OF
CONTAMINATED INERT WASTE

A. Basis for the Analysis

The basis for the analysis was the prototype contaminated waste incinerator described in a final report by Uniroyal, Inc.[5] and located at Joilet Army Ammunition Plant (JAAP). It consists of four basic process units: (1) a hopper, (2) a dual action ram charger, (3) a dual chamber furnace and (4) a stack. A sketch of the system appears on Figure 6. Shredded cardboard and paper that previously contained explosive or propellant materials are visually inspected prior to addition to the hopper and subsequent combustion in the furnace.

B. Hazard Evaluation of the Design Concept

Three fuel sources were considered for the undesired event of "fire or explosion resulting in equipment damage or personnel death or injury." The most plausible was propellant or explosive material. It could be present in sufficient quantity as a cloud or a layer if the operator did not check the materials in process and remove undesired material. Three examples of possible contaminants were selected as being typical: M1 propellant, TNT, and N5 propellant. Other fuel sources were natural gas and fuel oil. Natural gas is used in the existing furnace although fuel oil might be used in some future design or possibly in a modification to the existing furnace.

Two sets of initiation modes were defined for propellant or explosive materials, one for a dust cloud and the other for a dust layer. Impingement, thermal, ESD, and electrical power discharge modes were evaluated as potential initiation modes for a cloud of combustible. Impact, friction, thermal, ESD, and electrical power discharge modes applied to a combustible layer. These are discussed in detail in the hazard analysis report (Volume I).

1. Hopper

The hopper is attached directly to the top of the dual action ram charger and acts as a temporary holding container for the ingredients.

Two potential sequences are unacceptable as analyzed, based on the 10^{-6} incident probability. Both have an overall probability of 10^{-4} and relate to a buildup of an explosive or propellant layer inside the hopper prior to maintenance. A probability of 10^{-4} was assigned to the existence of a sufficient layer since its presence is dependent on the operator not removing contaminants from the ingredients. An assumption was also made

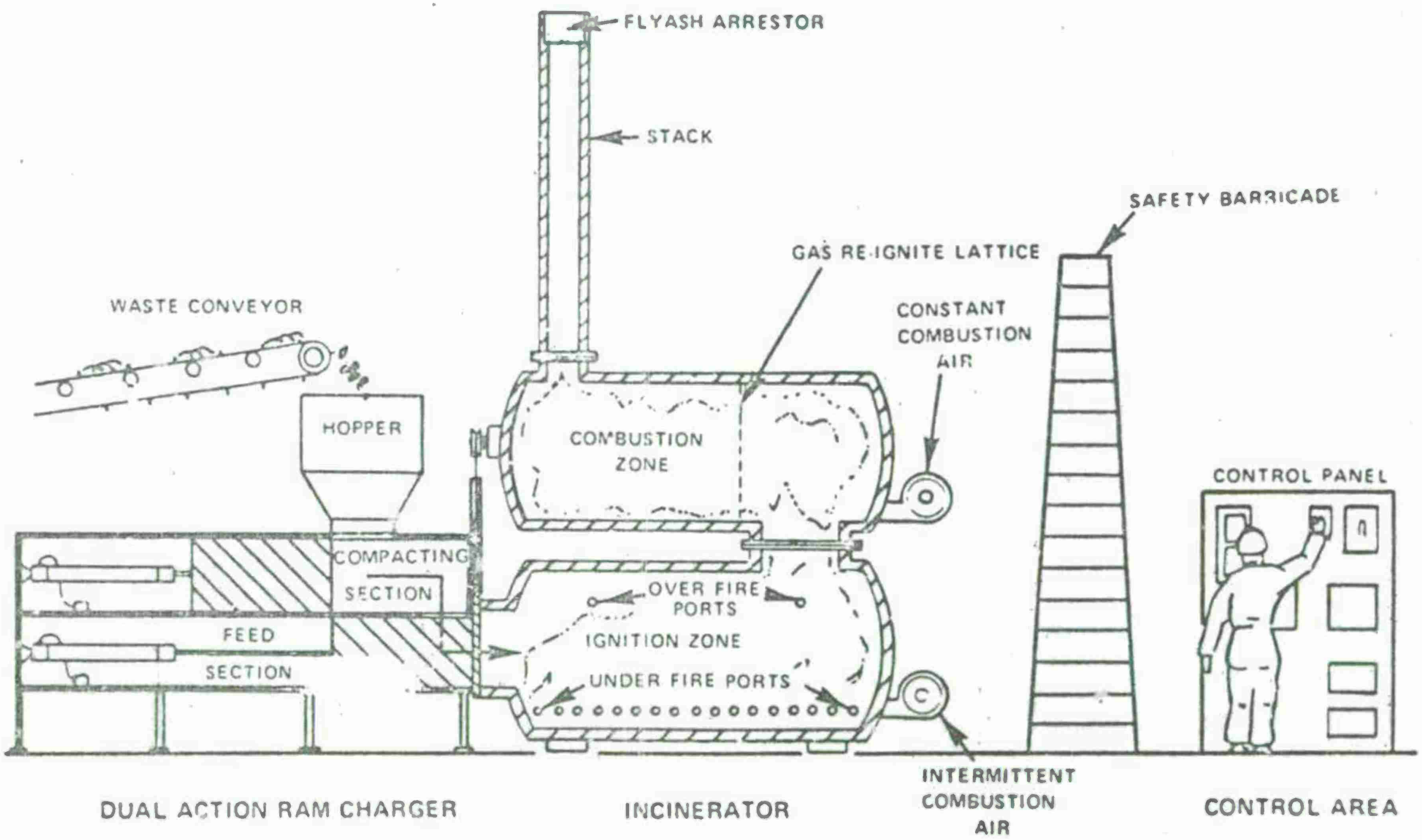

FIGURE 6

JAAP Contaminated Inert Waste Incinerator
(Environmental Control Products, Inc.)

that no check would be made for presence of a layer of combustible in the hopper prior to maintenance. Thermal or frictional initiation could occur during maintenance. A probability of one was assigned to this event. The thermal initiation mode which could occur during welding would be sufficient to ignite any explosive or propellant. Frictional initiation could occur if a tool is rubbed over a layer of combustible during maintenance. Generation of sufficient energy from a frictional stimulus, however, is dependent on both the stresses developed at a particular applied velocity, and the explosive material. When the stress was estimated to be three times the yield strength of the stainless steel vessel, both M1 and N5 propellant had zero safety margins, and therefore, a probability of one that the energy generated would be sufficient to ignite a combustible. TNT, however, has a positive safety margin (0.51) at this stress and consequently a probability less than one. At a stress equal to the yield strength, only N5 propellant had a zero safety margin; M1 and TNT had safety margins of 1.86 and 3.52 respectively.

If an examination were made of the hopper to see whether an explosive layer existed prior to maintenance, and it were removed if it existed, then a lower probability would be assigned to the existence of combustible which is subject to initiation by thermal or friction stimulus during maintenance. The overall probability of the undesired event would thus become very low and the hazard classified as acceptable.

a) Future Analysis Requirements

(1) Engineering Design Phase

During Engineering Design Phase, a detailed analysis of the hopper system should be completed to increase the safety margins in this area. Also, an analysis of the feed conveyor system should be made.

2. Dual Action Ram Charger

The dual action ram charger consists of two piston sections which operate in tandem. The first section is the compacting section. It receives the feed from the hopper and crushes material by forward motion of its piston. The second section is directly below the compacting section and is the feed section. It receives the crushed ingredients from the compacting section and pushes them into the furnace by moving its position forward. These units are equipped with two 3 hp motors actuating chain and sprocket driver rams, pressure sensitive switches to prevent jamming and initiate recycling, a flame detection device, and controlled water spray for fire protection.

Three sequences are unacceptable. Each has a high probability of occurring and required buildup of an explosive or propellant layer inside the charger. The same assumptions were made concerning the buildup of this layer as in the hopper. A probability of 10^{-4} was assigned to the existence of a sufficient layer since its presence was dependent on the operator not removing the contaminants from the feed material. In

addition, the same assumption was made that no check would be made for the existence of a layer in the hopper prior to either maintenance or normal operation. The presence and sufficiency of frictional and thermal initiation modes (as discussed in the hopper section) apply here. Consequently the same corrective action could be taken to make the hazards acceptable. The third initiation stimulus was heat generated by the adjacent furnace. Periodic cleaning of the system and not opening the loading door until the temperature is less than 100°C, would be required to make this hazard acceptable.

a) Future Analysis Requirements

The recommendations for future analysis are the same as for the hopper system.

3. Dual Chamber Furnace

The dual chamber furnace operates as an induced draft incinerator and consists of two vessels positioned horizontally, one over the other. The lower chamber, called the ignition chamber, receives feed from the charger through an interlock loading door which prevents exposing the charger to "excessive" temperatures. It is equipped with fire ports and an intermittent combustion blower and operates under negative pressure. The second chamber is slightly smaller and is called the combustion chamber. The ignited product is drawn from the lower chamber into the upper chamber. The upper chamber is equipped with a constant combustion air blower and a lattice section for mixing and reigniting the gases.

A summary of potential initiation modes considered is available in Volume I, with their safety margins and probabilities and with the maximum probability for the presence of sufficient flammable material.

a) Stack

The stack is attached to the top of the combustion chamber of the furnace. At the top of the stack is a stainless steel fly ash arrestor.

As with the furnace, all sequences had low incident probability. The principal reason is the lack of fuel in this location. Simultaneous triple failures would be required in all instances for the undesired event to occur, since the feed to the stack is the combustion products of the furnace. An additional 10^{-4} probability is assigned to the accidental situation that sufficient fuel, e.g., explosive or natural gas, would not complete combustion in the furnace.

b) Future Analysis for the Furnace and Stack

No need for future analysis is anticipated.

c) Hazard Criteria

Due to the potential hazard in the hopper/ram area, this unit is assigned a Category III hazard.